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Mobile Gateway for Wireless Sensor Networks utilizing drones

by

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Abstract

Keywords Wireless Sensor Networks, task, scheduling, graph cuts

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Chapter 1

Introduction

Technology has been present in our lives for a long time and we have become so accustomed to it that we do not even realize when we are using it.

This technological advance has lead to inventing small devices with low power consumption and communication capabilities. They form a wireless sensor network and can be used to collect data from the environment and send them to a gateway for further processing. In a way, even the new gadgets that have appeared this year, gadgets like smartwatches and fitness trackers, can be seen as wireless sensor devices because they collect data like steps, heart rate and have wireless capabilities.

The applications of a wireless sensor network are unlimited in number. For example they can be used to monitor crops, to detect possible forest fires, to detect the presence of animals or vehicles in certain areas, tracking and monitoring doctors in hospitals, guidance interactive toys, detecting and monitoring car thefts etc. In the last ten years, integration of wireless sensor networks with unmanned aerial vehicles had been tested and proven to be successful. So far, the proposed implementations , described in chapter 2, are complicated, difficult to operate and too expensive for the general public.

The solution that we propose is based on a very popular, easy to use AR Parrot Drone 2.0 and the Sparrow Family [VTD13], developed at Polytechnic University of Bucharest by Andrei Voinescu.

Chapter 2

Related Work

The related work is starting to expand and new researches propose new ideas, but generally speaking they tend to focus on ways of collecting the data from the nodes. The objective in their articles is to see if an UAV can be integrated with a wireless sensor network. The conclusion is generally positive, but a big problem in adopting their research in real life scenarios is represented by the high costs of the equipment they used and the necessary knowledge required to setup and operate the equipment.

The general experiments presented in the UAV and WSN integration research are the following:

- Using nodes signal to perform course corrections for dynamic navigation
- Data muling from nodes
- Using drones to deploy a new node in order to expand or to fix a problem in the network
- Using drones to determine ground military activity [ASSC02]

2.1 Standard WSN Protocols

The protocols implemented in Wireless Sensor Network are based on surrounding node discovery in order to build a topology and find the best way they can multihop data to the gateway. This approach works best in a static environment, but in a dynamic environment or an environment where the distance between nodes is too big or the time between two data packets is too big, the network convergence will be slow or not even possible.

2.2 UAV experiments with Wireless Sensor Networks

[TMCH08]

The experiment consisted of using ground nodes that had a gps position assigned. The UAV plane would perform course correction after receiving the current gps position from the node in order to calculate the best path for muling the data from the nodes.

The advantage of using a plane used for the experiment is the longer range and higher speed that it can offer against a quadcopter or a similar design. But the high speed creates the problem of maneuverability. The plane has a turning range of 400 meters while the drone can almost turn on the same spot.

2.3 Crop Monitoring

[VSB⁺11]

A research of using a drone for crop monitoring has been conducted at a vineyard. Their system was comprised of a unmanned quadcopter, an Arduino board with a GPRS module for long distance communication with the drone and ZigBee and Crossbows TelosB as wireless sensing nodes. The drone was not controlled via the long-distance link, but through a Spektrum DX7SE 2.4 GHz remote control.

They demonstrated that a preprogrammed UAV can be used to monitor multiple crops where a standard WSN could not be deployed because of the unique constraints imposed by the environment.

The cost of the implementation was relatively high compared to ours, the remote is 300\$, the same as the entire drone that we propose and the TelosB is 99\$. This data suggests that for their experiment the drone, communication module and the remote control were half the cost of the equipment.

Another problem was that they were not saving the data locally, but sending it back to the base station where it was processed and saved. This can represent a problem because the system cannot function properly unless a base station is supplied.

2.4 Aware platform

[OBLC⁺07]

The Aware platform, proposed by Ays. Egl Tysz Erman, Lodewijk Van Hoesel and Paul Havinga from University of Twente, is a platform that integrates WSNs, UAVs, and actuators into a disaster response setting and provides facilities for event detection, autonomous network repair by UAVs, and quick response by integrated operational forces.

They use multiple UAVs to deploy new nodes that will replace the damaged ones and check if they function. The entire system still relies on a sink to collect the data and to send them to a base station.[[EHHW08](#)]

Chapter 3

Hardware Platform

In this chapter we will present the hardware platforms used.

Because we wanted to emphasise not only a new way of aquiring data, but also a simple and low cost one, we have selected The Parrot AR.Drone 2.0 as the work horse that will carry the mobile gateway which communicates with the nodes from our Sparrow Family. The drone provides several key features that we require, such as a Linux embedded system, a mobile platform with the possibility of autonomous flying and sufficient flight time for our needs.

In order to keep the price low and a small footprint, the Sparrow Family has a sourface mounted antena on the pcb. The power of the antenna is 2 dbi and it is perfect for applications were size is a constraint. When the size can be overlooked, an external antenna can be monted to extend the range of the device.

3.1 The Parrot AR.Drone 2.0

[Par12]

Parrot AR.Drone is a WiFi radio controlled flying quadcopter built by the French company Parrot. The original drone was released in 2010 and in 2012 it was replaced by version 2.0. Since the launch of the original AR.Drone, more the half a milion units have been sold, making it one of the, if not, the most popular drone on the market.[BRA13]

The reason of its success is not entirely due to the relatively low price of around 300\$ but also because it is very easy to learn how to control the drone and also because of the USB port that accommodate any device using that interface and the Linux operating system, making it incredibly versatile and very easy to integrate in our system.

Because of those reasons, the Drone has a number of after-market modules that can be attached to it, such as the Flight Recorder GPS Module. This module



Figure 3.1: *The Parrot AR.Drone 2.0*

has a built-in storage of 4GB for video recording purposes and a built in GPS receiver. This allows the drone to follow a predetermined path of waypoints and to return back from where it took off automatically, all within the limit of the Wi-Fi connection with the control device.

In order to properly accommodate the Sparrow Dongle, the hull had to be carved. Also the required external antenna of the dongle was mounted on top of the polyester cover and a small counterweight has been glued at the opposite side in which the dongle is located. The counterweight acts as a balance that keeps the drone level.

The arrot AR.Drone 2.0 specifications are :

- 1GHz 32 bit ARM Cortex A8 processor with 800MHz video DSP TMS320DMC64x
- Linux 2.6.32
- 1Gbit DDR2 RAM at 200MHz
- USB 2.0 high speed for extensions
- Wi-Fi b,g,n
- 3 axis gyroscope 2000/second precision
- 3 axis accelerometer +-50mg precision
- 3 axis magnetometer 6 precision
- Pressure sensor +/- 10 Pa precision

- Ultrasound sensors for ground altitude measurement
- 60 fps vertical QVGA camera for ground speed measurement
- 30 fps 720p front mounted camera

3.2 The Sparrow Family



Figure 3.2: The Sparrow Dongle next to the SparrowV3.2

The Sparrow Family, composed of the Sparrow Dongle and SparrowV3.2, use a 2.4 GHz wireless network as a medium of communication.

The main component of this family is the ATMega128RFA1. It is an 8bit micro-controller from Atmel that has an on-chip 2.4 GHz wireless transceiver. On-chip transceivers occupy no extra space and require little extra electronics to operate, making the resulting boards very small. The on-chip transceiver allows more energy-efficient operating modes, and facilitate higher bandwidth transfers between the micro-controller's main memory and the transceiver frame-buffer, all of which are important improvements in the field of wireless sensor networks.

The signal received or sent by the wireless transceiver can be boosted by attaching an external antenna. For example, in an ideal situation, with no interferences from the outside world , an 8-dBi omni-directional antenna mounted on both communication devices would amount to an around 200 meters of communication range, well over the 70 meters measured with the default antennas.

3.2.1 The Sparrow Dongle

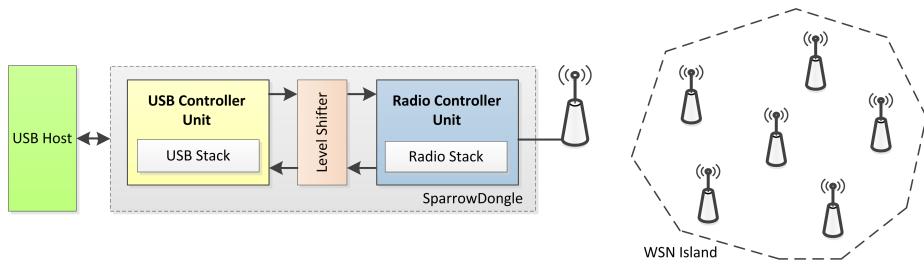


Figure 3.3: *SparrowDongle stick architecture*

The link between the the wireless sensor networks and the rest of the digital world, the Sparrow Dongle is the gateway of the Sparrow Family. The Dongle can be connected to any device that has an USB port and can support USB CDC with ACM module (USB Communications Device Class with Abstract Control Mode).

The dongle uses Atmega32U4 as a dedicated USB Controller unit. This design allows the RF controller to run any RF communication stack without having the USB code intrude on key timings.[[VTD13](#)]

3.2.2 The SparrowV3.2

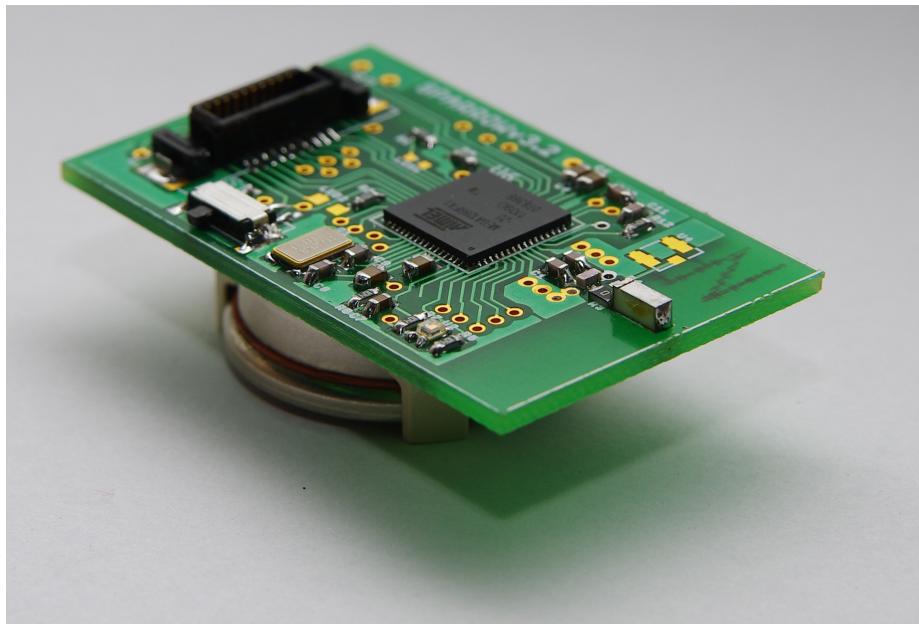


Figure 3.4: *The SparrowV3.2*

The other member of The Sparrow Family, the SparrowV32 nodes are responsible of collecting data from the surrounding environment and sending it to the Sparrow Dongle. The collected data depends on the sensors attached to the SparrowV3.2. The standard implementation has a light, temperature and humidity sensor. Besides this information, it also sends the battery level.

The SparrowV32 can be modified by adding additional sensors for a better understanding of the environment.

Chapter 4

Software Implementation

The solution is divided into different modules that run independently but communicate with each other to achieve the main goal. The separation of software modules allows for future features to be added easily.

The main modules are installed in the AR Parrot Drone and the Android FreeFlight 2.0 application.

The SparrowDongle gateway is always in a listen-for-data state and dumps any data received on the serial. When it receives the data, it sends back an ACK message back to let the SparrowV3.2 node to know that it can begin sending the entire stored data to the mobile gateway.

The SparrowV3.2 node is sending periodically a small data packet to check if a gateway is available. It stores the data accumulated over the period when no reply is given to it. When it receives the ACK message from a mobile gateway it starts sending the stored data to the gateway. The data sent can vary, from sensor readings to debugging information in order to check the state of the Wireless Sensor Network.

The data gathered by the gateway is saved into different files in the AR Parrot Drone's internal memory. The files also contains information such as the node identification tag and time of the transfer. The data can be accessed at any time by any device connected to the drone's wireless network port 4242 via FTP.

The drone also processes some of the collected data to provide realtime HUD information, such as signal strength, last connection time and number of discovered nodes. This information is sent to the controlling device through a socket connection.

The controlling device, pc or android, will gather the information and display them to the user.

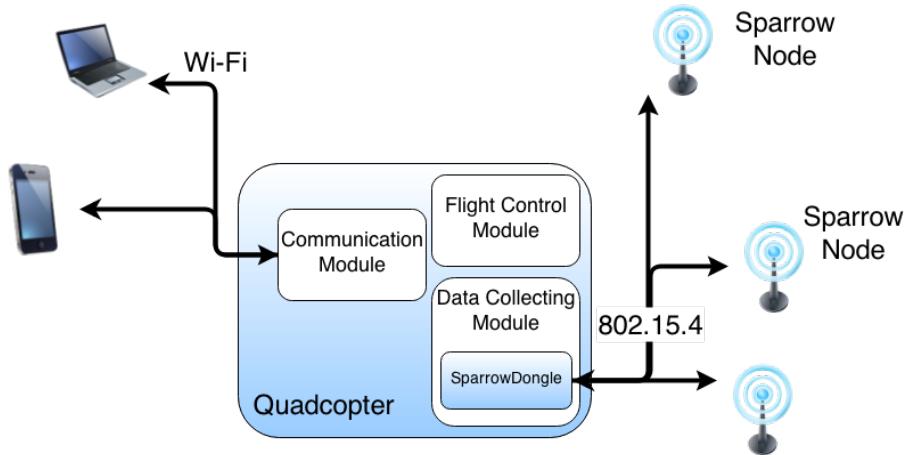


Figure 4.1: *Modules and connections between them and devices*

4.1 The Debug Module

When performing modification to the existing code, a debug enabling option would speed up the process. The module would allow for displaying control message to the user console even when the process is running in background. If the messages would be activated all the time, they would slow down the execution speed of the process.

In order to see those messages, the debug option must be activated and then this simple command will show them:

Listing 4.1: Simple display message command

```
p=$(pidof read) && strace -p $p
```

Enabling the debug is just a matter of setting a define from 0 to 1, recompile and upload the code to the drone to see the messages.

Listing 4.2: Data Collection use of mutex

```
/* activates/deactivates printf debug information */
#define DEBUG_ON 0
/* delay time in microseconds */
#define DELAY_US 100000
#define DEBUG_PRINT(a...) { if(DEBUG_ON) printf(a); }
```

In certain parts of the modules a sleep action is needed in order to wait for an action to be executed. The value can be changed to any level, but you must be careful in doing this. A small delay will send data more often but it could

use a lot of processing power, while a big delay could be too slow for the data to be usable. Now the delay is set at 100 ms, for a 10 times per second data update.

4.2 The Data Collecting Module

The module saves the collected data into the drone's internal memory and passes the data on to the communication module, which will display on the controller interface certain data: number of nodes currently connected to the Dongle, de signal strength, if the Dongle is connected etc.

This module, besides the main purpose and similar to the other modules, has some extra features that are designed to make the solution more user friendly and easier to improve in the future.

4.2.1 Modules intercommunication

The memory area in which the information sent to the user is saved is shared between this module and the communication module. The interaction method between these two modules belongs to the consumer-producer archetype, where the Data Collecting Module can be associated with the producer side and the Communication Module with the consumer side.

A sensible issue with this approach regards possible deadlocks. This is prevented with the use of a mutex construct that allows only one thread at a time to modify the data.

Listing 4.3: Data Collection use of mutex

```
pthread_mutex_lock(&data_lock);
add_node_data(get_current_timestamp(), read_data + 7);
pthread_mutex_unlock(&data_lock);
```

The mutex is used similarly in the Communication Module when it consumes the information.

4.2.2 Fault tolerance

Because the Dongle is connected to an USB port on a machine that has a lot of vibrations, it might disconnect / reconnect for a very short period of time, so this module has been designed with multiple USB disconnects and reconnects without the need to reset the Drone. This information is vital, because you can check if the Dongle is still connected to the drone without the need to inspect it visually or to connect to a debug terminal.

Besides the possible dongle usb disconnects, an out of range signal loss may be experienced. If this happens, the drone will hover until the connection is reestablished.

4.3 The Communication Module

All of the information gathered by the Data Collecting Module would be useless if it cannot be accessed easily.

This module, as the name suggests, handles the communication of this crucial information back to the user.

Being a different module, with different attributions than the Data Collecting Module, it has an entire Linux process dedicated to it for 3 important reasons:

1. The approach of having a process per module allows the modules to run independently of each other;
2. The Data Collecting Module can collect the data from the Dongle as soon as this is available;
3. If the Communication Module stops working, the Data Collecting Module can keep collecting data, so complete failure of the system is avoided;
4. System processes can be restarted in case of failure.

4.3.1 Socket with connection reset

The communication is done through socket connections listening on port 8888. The server running on the drone accepts only one connection at a time.

If a connected client decides to disconnect before or while a write operation is in progress, a SIGPIPE error signal will be thrown, stopping all the modules. This is prevented by ignoring the signal, forcing the write action to return a EPIPE, and exiting gracefully.

The main process will use the callback `accept_socket_connection` to reestablish a new connection. Once a connection is established, it will send information once every `DELAY_US` microseconds. The program was configured and tested with a 100 ms wait period that leads to a ten times per second information update.

This delay is required because:

- If data is send too often, the socket might be flooded and stop sending the data.
- If there was no delay, it would occupy too much processor time both for the drone and the controlling device.

4.3.2 JSON Encoding of Data

[jsn]

JSON is an open-standard that uses text to encode data and it is an alternative to XML. Derived from the javascript scripting language, it is a language-independend data format available in most of the programing languages.

JSON is best suitable for this application as a data encode format because it is data oriented, unlike XML which is document oriented. Also it is very easy to encode because it has a code like structure, the result is smaller than the XML alternative and all devices can decode it.

The informations encoded by the drone are:

- Dongle connection status
- An array containing node data
 - Node unique ID
 - Last connection time of the node to Dongle
 - The power of the received signal

4.4 Android application modules

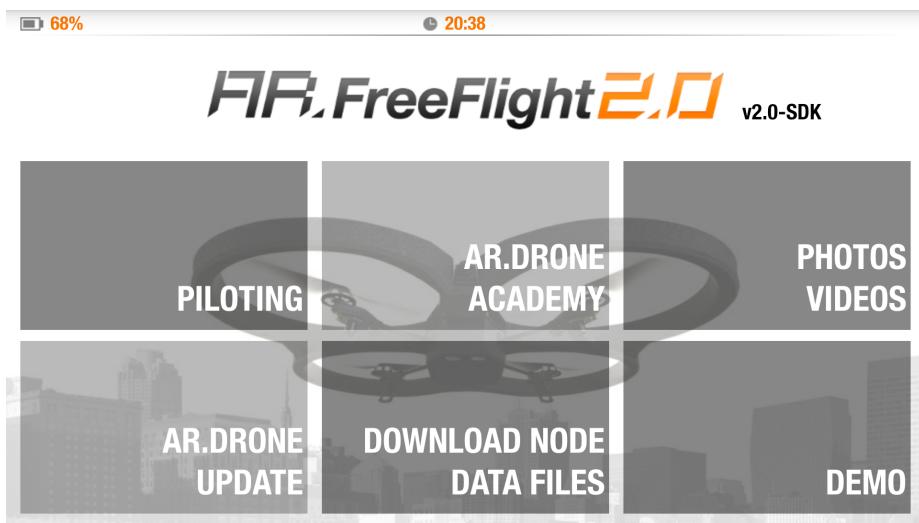


Figure 4.2: *ARFreeflight modified application*

Being an open-source platform we have modified the AR Freeflight 2.0 Android application to communication with our new modules added to the drone.

Android fairly imposes the use of the background process class AsyncTask when you have to use communication protocols like http, ftp, sockets because this prevents the UI process from being stuck in communication and not responding to user actions.

The class offers 5 very important methods that can be overwritten, 3 running on the main UI process, that prepare data before and after execution, publish the progress or simply cancel at any step, and 1 running on the actual background process.

4.4.1 Display information module

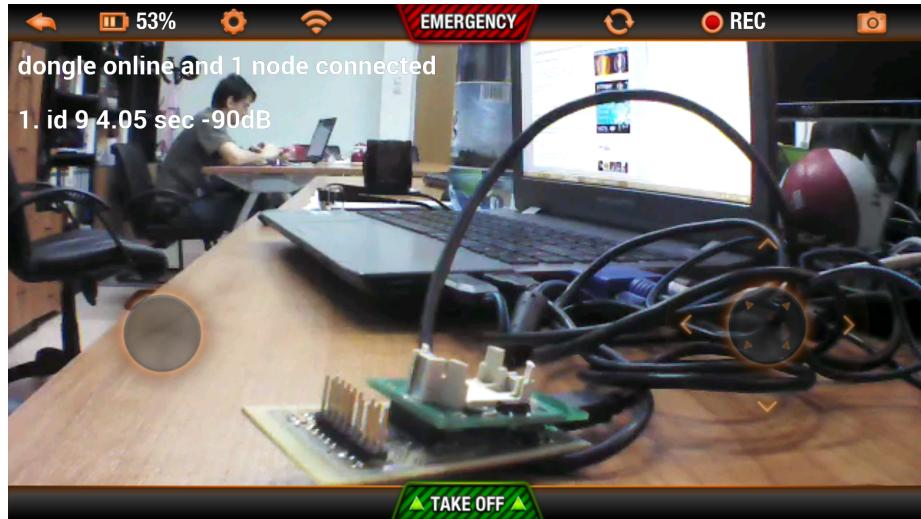


Figure 4.3: *ARFreeflight modified Piloting Screen*

The Piloting screen of the application has been modified to display the received data from the drone.

The information displayed is comprised of the state of the dongle being functional or not. Besides that, it can show the signal strength, unique id and last connection time of up to 9 nodes sorted descending after their signal strength.

4.4.2 FTP communication module

The drone has a built-in FTP server that can be configured to allow access to any folders/files on the drone. We have configured the drone so that the folder in which the data is saved can be accessed at any time using the 4242 port by any device that has FTP client capabilities.

This feature adds to the Android application as well to have a better out of the box experience.

The application will download all the files from the drone to the local storage of the user's Android device while displaying the progress.

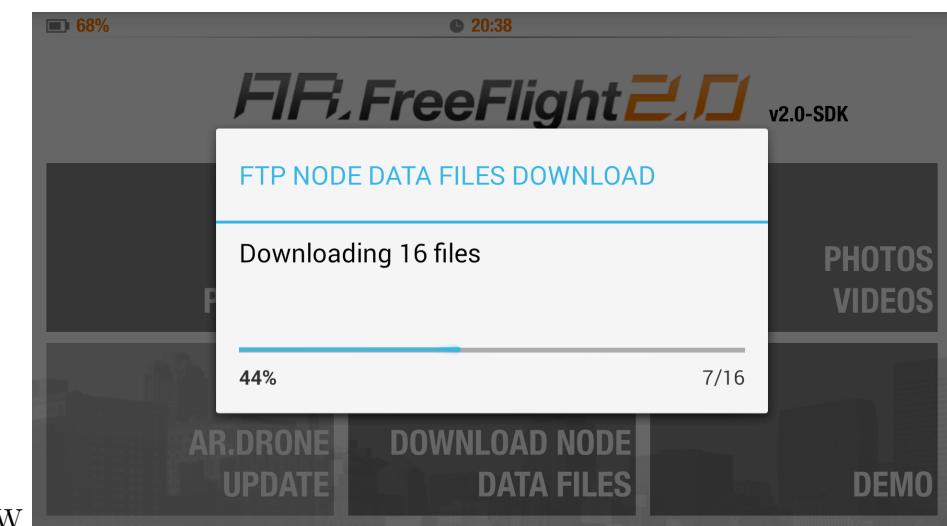


Figure 4.4: *ARFreeflight* FTP downloading files

Chapter 5

Testing

The tests that we have conducted highlights the strengths of the platform but also reveals some of its weaknesses. The most important characteristics of this experiment the maximum hight that the drone can achieve with extra gear, the maximum range of the wireless network and the maximum range of the dongle .

They show the maximum range at which a drone can still communicate with base or with a SparrowV3.2,

5.1 Scenario

5.2 Results

Chapter 6

Future Work

Even though the solution is working, new application and functionalities can be added. The application can be from opposing worlds, such as search and rescue versus military.

6.1 Features

6.1.1 Debug

A feature that can be used in conventional wireless sensor networks is to determine the source of communication failure. If the gateway detects that the network has a communication problem and not all of the previous nodes can be reached, this information will be send to the drone and it will try to find and determine which nodes are working properly and which nodes are not.

6.1.2 Truly Autonomous flight

The AR Parrot Drone 2.0 can perform autonomous flight with a GPS module, but only while it is still in the range of the WiFi connection.

6.2 Applications

6.2.1 Treasure Hunt Games

A treasure hunt game can be played by placing the nodes with information regarding the location of the treasure at certain hidden spots and trying to find the treasure by following the clues provided by the drone.

6.2.2 Search and Rescue

When tourists go hiking or other similar activities and get lost they can be found if they are wearing a wireless sensor that monitor vitals and can gather a periodical GPS position. The drone will search for the signal emitted by the node and help pinpointing their exact location while offering a live video feed of them.

Chapter 7

Conclusions

7.1 Outlook

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